

Dark Interactions

Perspectives from Theory and Experiment

June 11-13, 2014

Brookhaven National Laboratory

<http://bnl.gov/di2014/>

Topics

- Theoretical Motivation for Dark Sectors
- Experimental Constraints from High Energy Colliders
- Constraints from non-Collider Experiments
- Cosmological Constraints
- Implications for Dark Matter
- Prospects for LHC Run 2 and future Intensity Frontier Experiments

The Organizing Committee

Ketevi A. Assamagan (Chair, BNL)
 Oliver Keith Baker (Yale University)
 Mary Bishai (BNL)
 John Paul Chou (Rutgers University)
 Hooman Davoudiasl (BNL)
 Rouven Essig (Stony Brook University)
 Tobias Golling (Yale University)
 William Marciano (BNL)
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BROOKHAVEN NATIONAL LABORATORY

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October 4 - 7, 2016

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Dark interactions workshops

- **Since 2014, we started a series of workshops at BNL on “Dark Interactions: perspective from theory and experiment”**
 - June 11-13, 2014, di2014:
<https://www.bnl.gov/di2014/>
 - October 4-7, 2016, di2016:
<https://www.bnl.gov/di2016/>
 - Next workshop, di2018 in 2018
- **Attendance at each workshop**
 - About 80 people, theorists and experimentalists
- **Format**
 - Plenary talks by invitation
 - Contributed talks in parallel sessions
 - Plenty of time for discussions

Goals

- **Search for several well-motivated dark-sector particles**
 - with existing and upcoming experiments
- **Propose new experiments**
 - that can lead to searches for dark forces in the coming decade
- **Since there is currently a vast range of possibilities for what could constitute the dark sector**
 - a variety of innovative approaches for answering this question need to be considered
- **To that end, the dark interactions workshops**
 - Are helpful as they facilitate the exchange of new ideas
 - Create an environment for in-depth discussions among theorists and experimentalists
- **Develop collaborations between BNL theorists and experimentalists**
 - On searches for dark sector states

Scope – invited talks

- **Overview of light dark sectors**
 - Theoretical motivation and phenomenology of light dark sector
 - Axions and ultra light dark photons: theory and searches
- **MeV-GeV dark matter**
 - Theory and beam dump experiments
 - Direct detections
- **Searches at the LHC**
 - Dark matter searches
 - Decays to dark sector particles
- **Dark sector searches at e+e- colliders**
- **Meson decay experiments**
- **Status of Dark Matter Direct Detections**
- **Cosmological and astrophysical probes of dark matter**
- **Neutral naturalness and hidden valley dark sectors**
- **Neutrinos and hidden physics**
 - Astrophysical probes of neutrinos
 - Neutrino anomalies
- **Future at the very large and small scales**
 - Future prospects in cosmology
 - Future prospects at colliders

Scope - Contributed talks – di2016

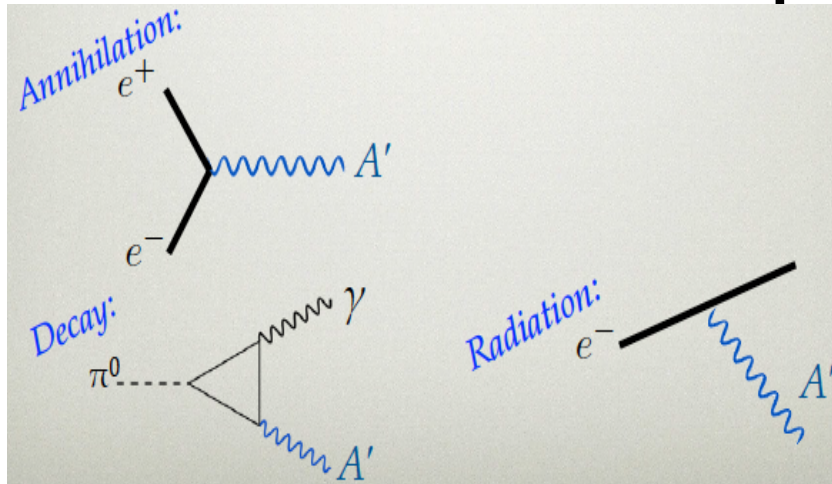
- **Experimental contributed talks**

- Recent results and prospects on Dark Interactions from CERN
 - NA48/2 and NA62 Experiments
- Search for Dark Photons at LHCb
- Search for Dark Particles at Belle and Belle II
- Updated Bounds on Light Hidden Sectors in Supernovae
- Dark Photon Search at the Fermilab SeaQuest Experiment
- Direct Search for Dark Photon and Dark Higgs in E-1067 at Fermilab

- **Theoretical contributed talks**

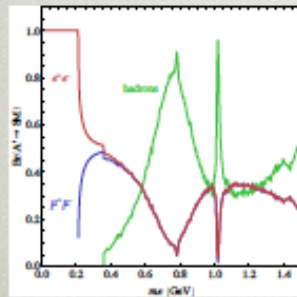
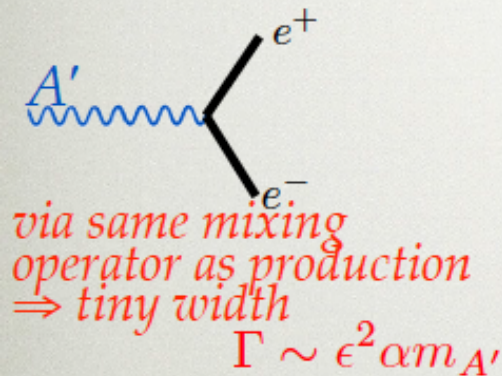
- Simplified DM models: a case with t-channel colored scalar mediators
- Dark matter models with two mediators
- Astrophysical Signatures of Dissipative Dark Matter
- Lattice Gauge Theory insights on Dark Matter
- Elastically Decoupling Relic (ELDER)

Dark Photon – production and decays

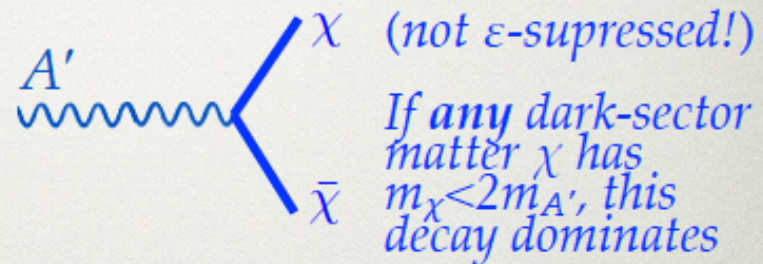


- Coupling $\sim q\epsilon e$, where ϵ is kinetic mixing parameter
- Need to search for both as searches for Dark Sectors and of light DM

“Minimal” Decay:



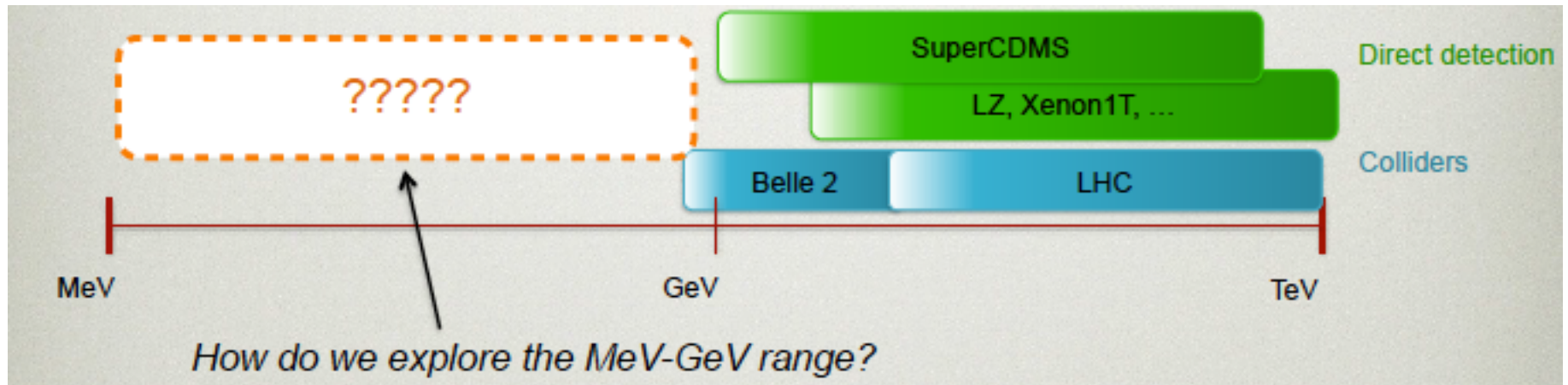
“Generic” Decay:



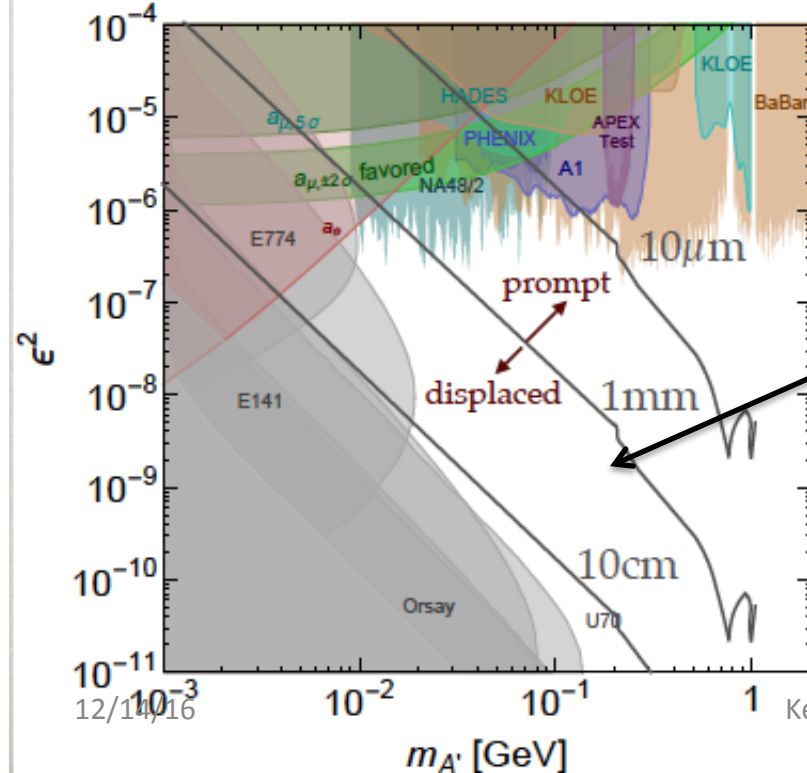
Two cases:

- χ stable & invisible
 - χ decays into SM particles, $A' \rightarrow >2$ charged particles
- searches at BaBar and KLOE

MeV-GeV Dark Photon

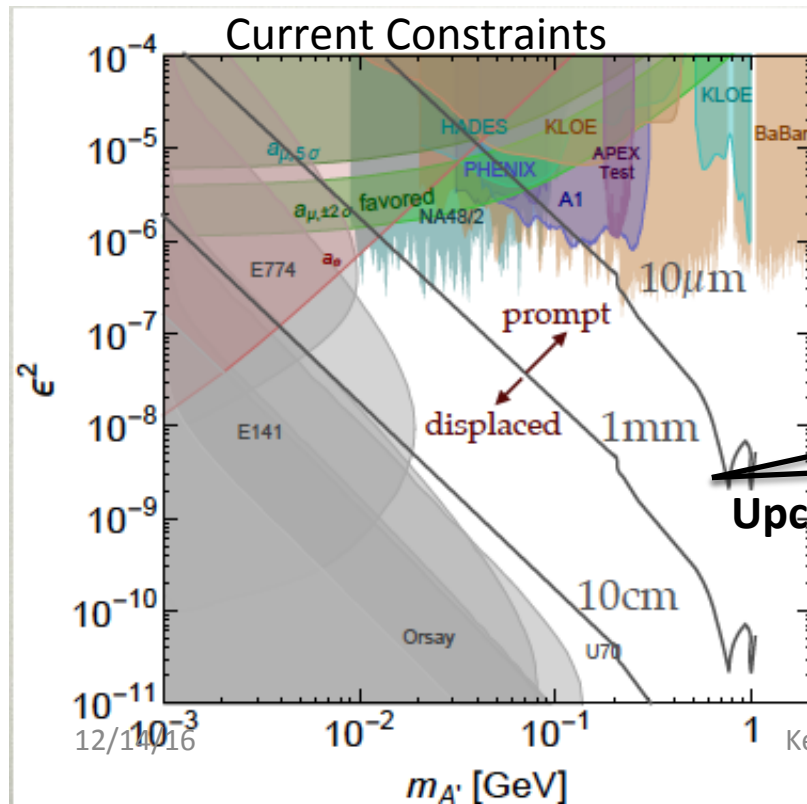
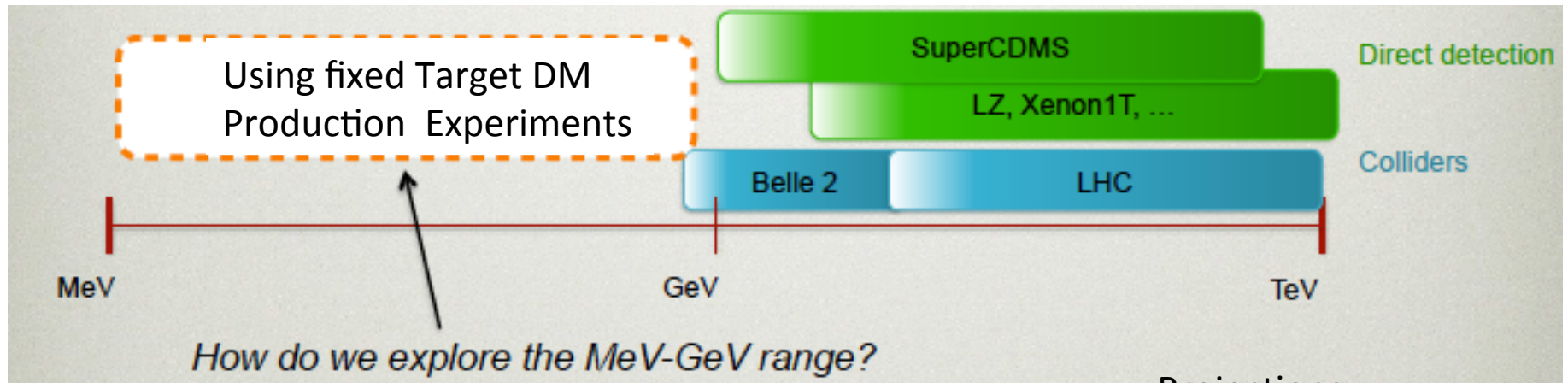


Current Constraints on dark sectors from visible decays



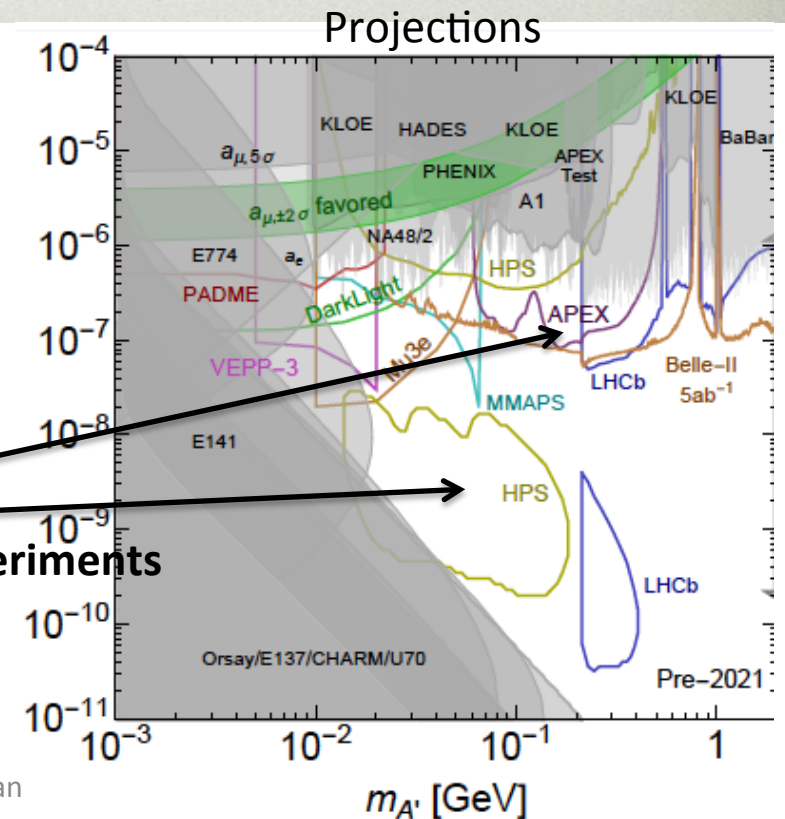
One key priority: extend the searches for visible decays

MeV-GeV Dark Photon

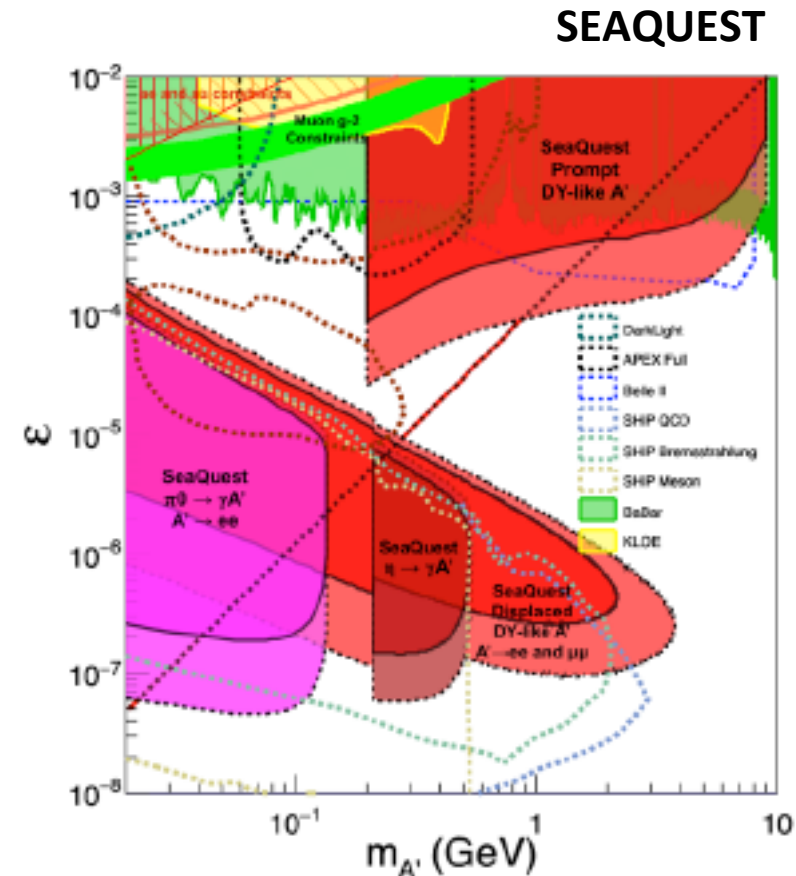
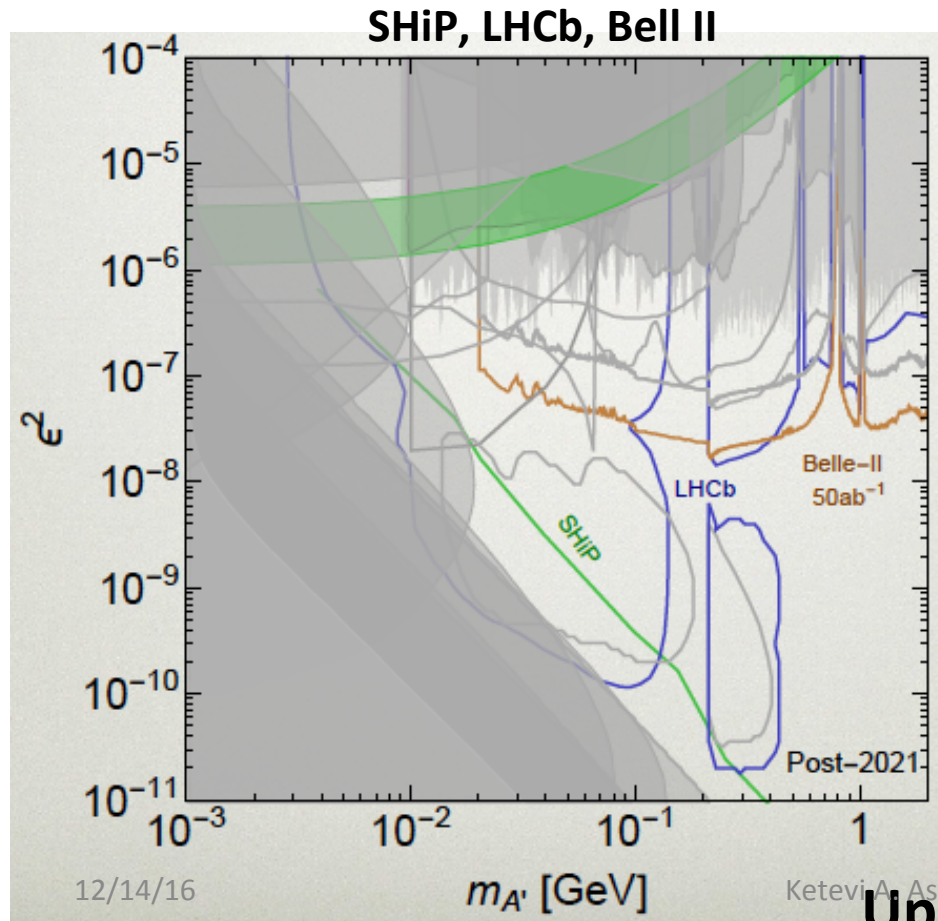
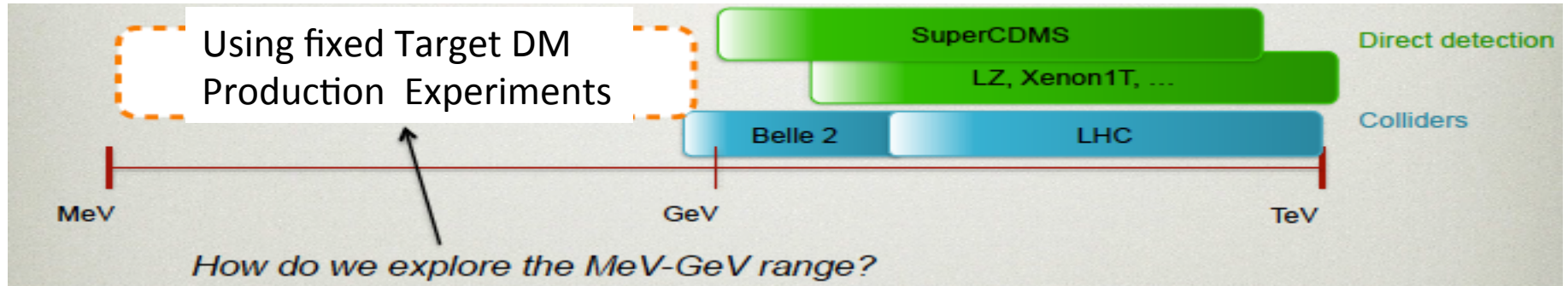


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Ketevi A. Assamagan

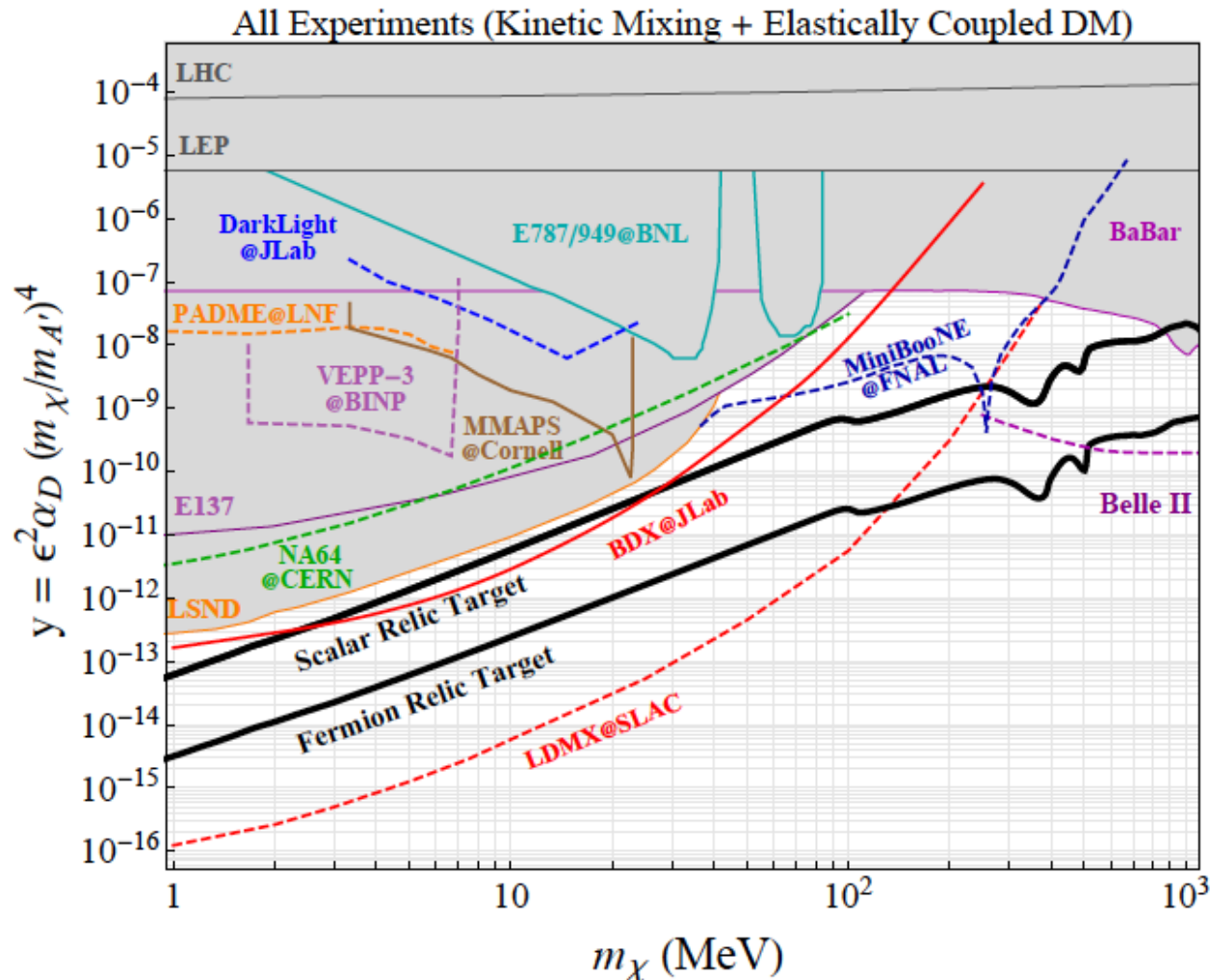


MeV-GeV Dark Photon



Upcoming Experiments

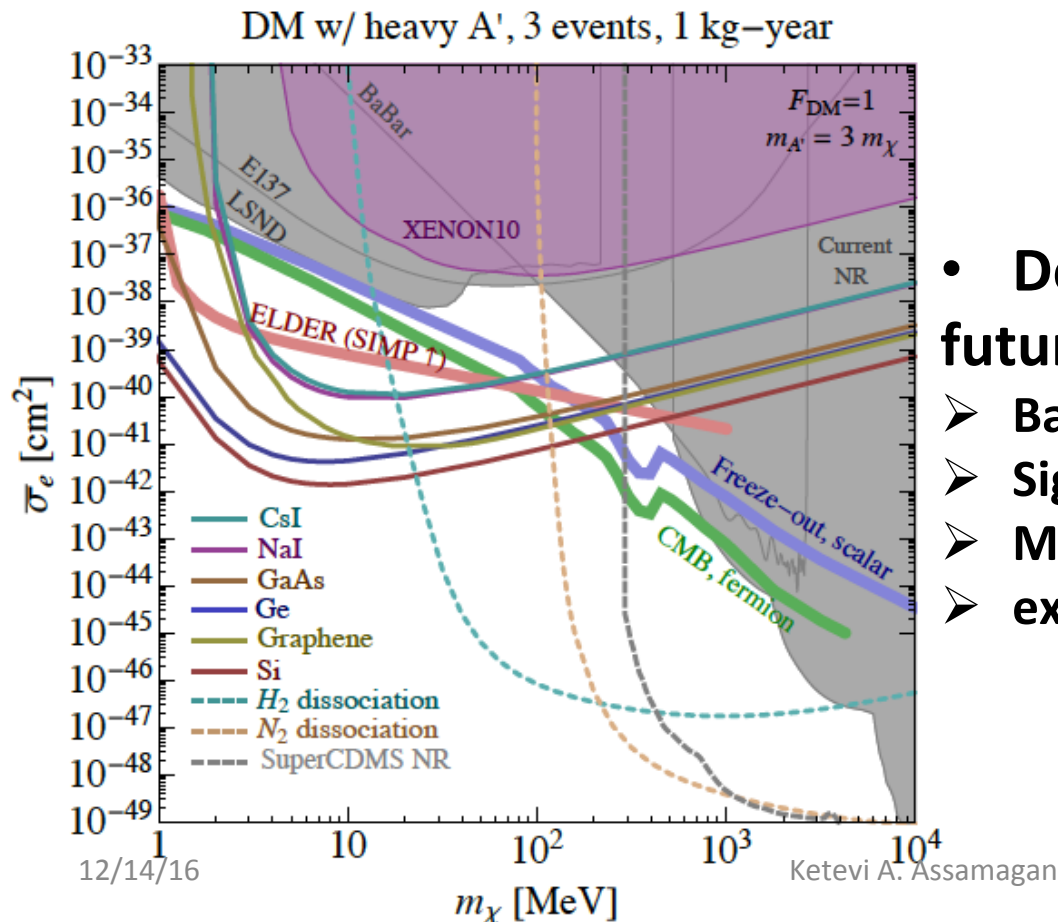
A case for fixed target DM production Experiments



Models for light thermal dark matter can be tested with fixed target DM production experiments – beyond the reach of direct detection and collider experiments

New Directions for DM Direct Detections

- Elastic nuclear recoil loses sensitivity for DM below a GeV
- New direction: search for DM scattering off of electrons instead of nucleus
 - Allows to probe DM masses well below a 1 GeV



$$m_\chi \gtrsim 250 \text{ keV} \times \frac{\Delta E_B}{1 \text{ eV}}$$

- Depends on the target material, future studies needed
 - Backgrounds
 - Signal vs backgrounds
 - Material fabrications and experimental designs

Conclusions

- **Key priorities**

- **Extend the searches/coverage of visible dark sector states to unexplored regions of the parameter space**
 - Many upcoming experiments
 - But more coverage of (1 GeV, low ϵ) range needed
- **Fixed target DM production experiments complementary to direct detection and collider experiments**
 - May even cover the parameter space beyond the reach of direct detection and collider experiments
 - Upcoming experiments (LDMX, BDX) in that direction, but still more coverage of the region (1-1000 GeV, low γ) needed
- **New Directions for direct detections**
 - DM scattering off of electrons instead of nucleus. Potentially improves the sensitivity of current direct detection experiments based on DM-nucleon scattering. R&D needed in material fabrications, backgrounds and signal vs background studies

- **Could be explored (not discussed here)**

- Inelastic DM-nucleon scattering: breaking of chemical bonds in molecules, multi-phonon processes in insulating crystals or superfluid helium, photon emission in nuclear recoil could produce signal sensitivity down to a KeV – GeV